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Published in:
Proceedings

Publication date:
2011

Document Version
Publisher's PDF, also known as Version of record

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Citation (APA):
Hahmann, A. N. (2011). From trades to turbines - linking global, mesoscale, and local models. In *Proceedings*
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From trades to turbines – linking global, mesoscale, and local models

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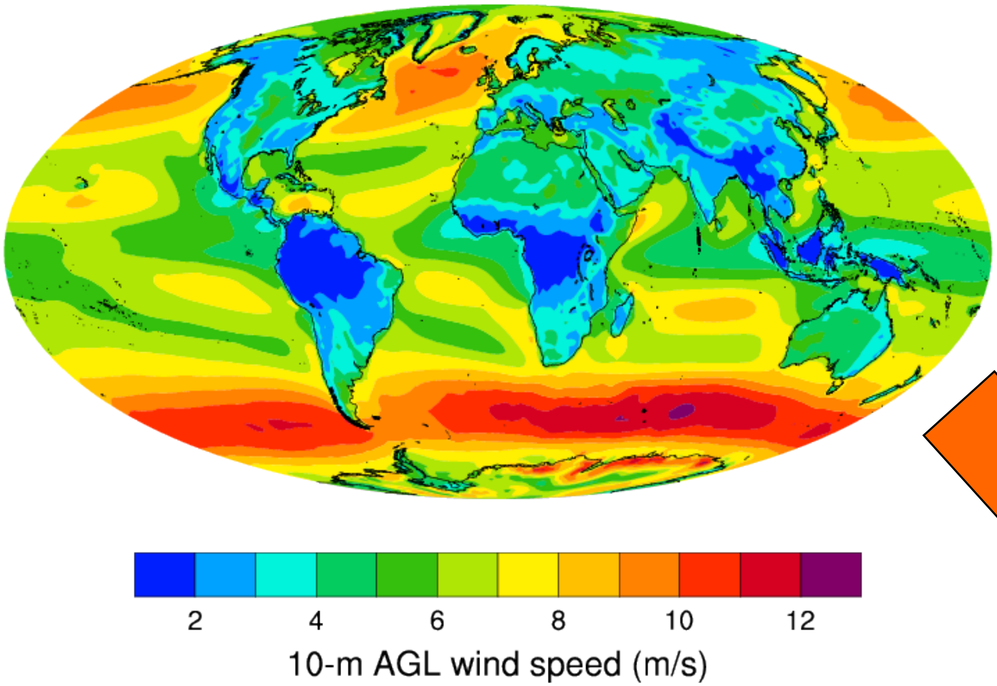
With many thanks to

Jake Badger, Alfredo Peña, Xiaoli Larsen, Claire Vincent, Caroline Draxl, Mark Kelly, Jens Carsten Hansen and Niels Gylling Mortensen

Outline

- The problem – an introduction
- From large-scale to mesoscale
  - Statistical-dynamical downscaling
  - Dynamical downscaling
- From mesoscale to microscale
  - The effects of resolution
  - How to use the mesoscale model information
  - Generalization
- Implications for verification
- Other applications
- Summary

ERA Interim reanalysis averaged winds (1989-2009)

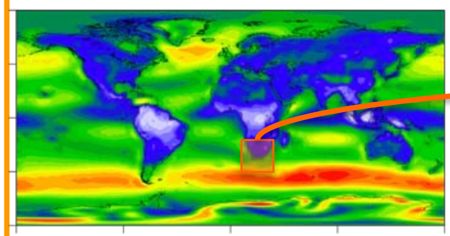


?

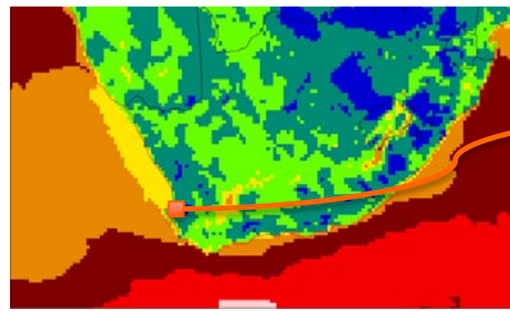
Horns Rev wind farm

Numerical Wind Atlas - Downscaling steps

Global



Regional



Local

Mesoscale modeling

KAMM/WAsP, MM5, WRF, etc.

Microscale modeling

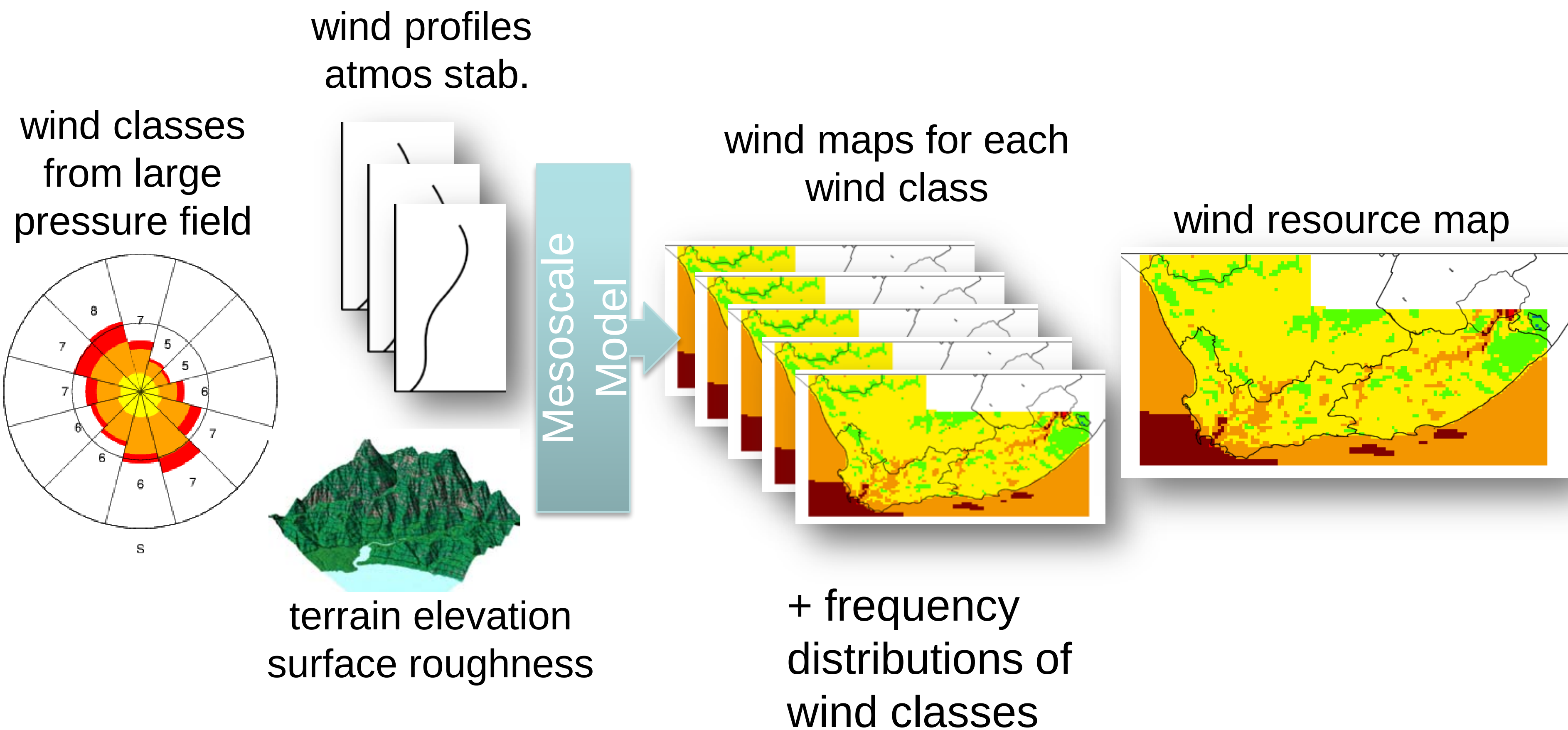
(WAsP, other linear/nonlinear models)

For now we assume that the models are perfect, and concentrate on their coupling

KAMM: Karlsruher non-hydrostatic mesoscale model

WAsP: Wind Atlas Analysis and Application (widely used wind resource tool)

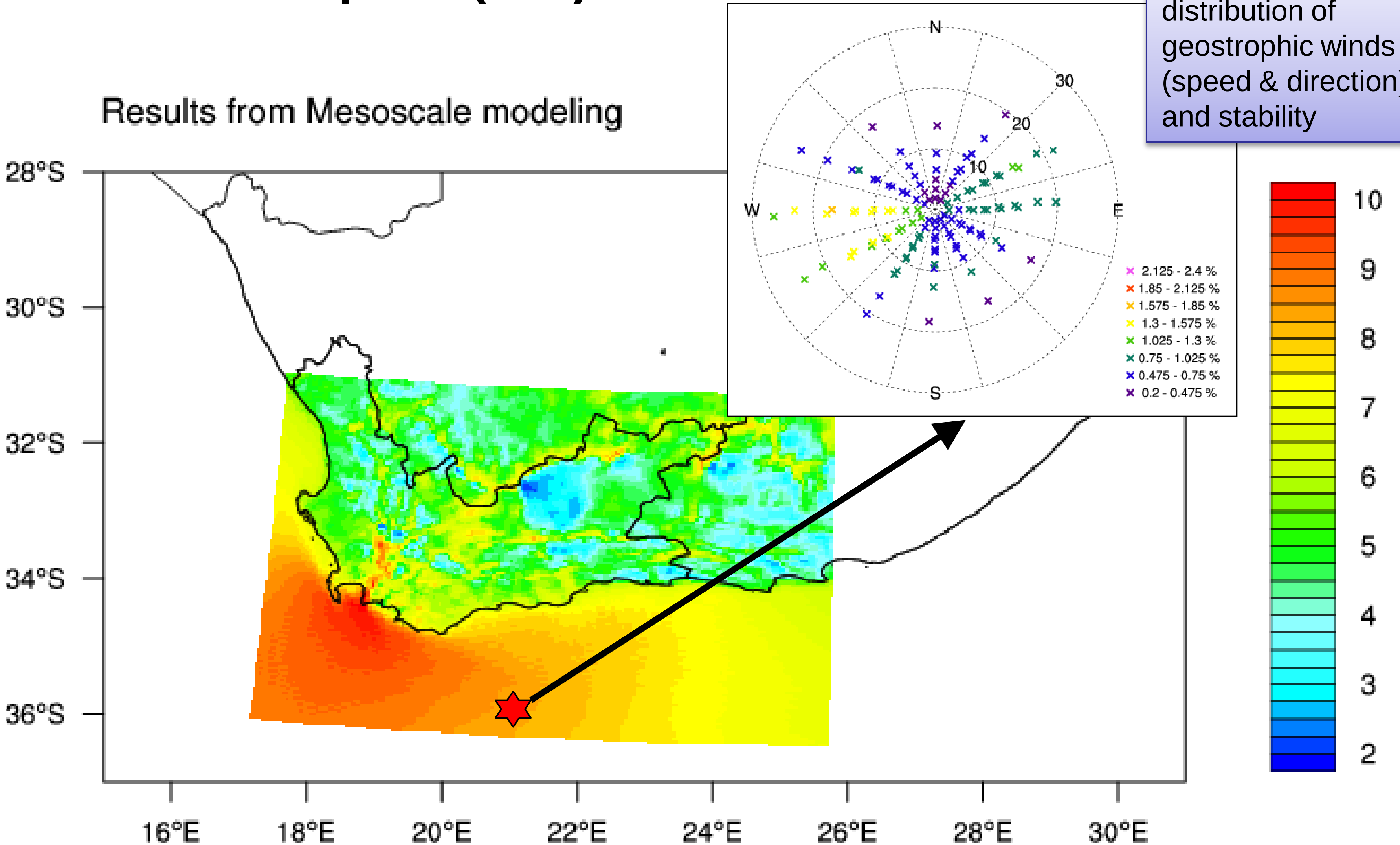
From large-scale to mesoscale: statistical downscaling



Simple/Fast/Cheap — Complex/Slow/Expensive

~~Interpolation~~ | Risø Wind Atlas | Statistical-dynamical | Fully dynamical

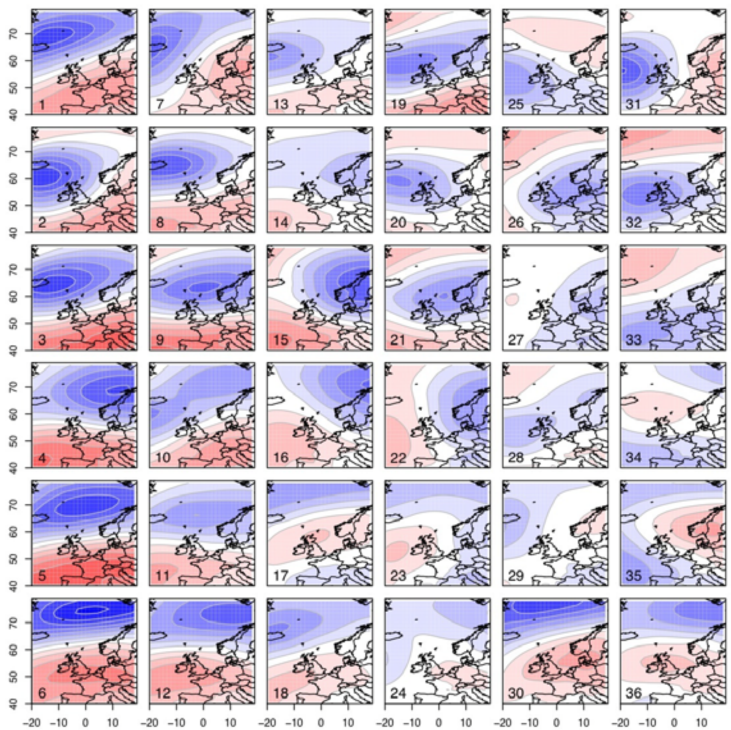
Preliminary calculations for South Africa Mean wind speed (m/s) at 50 m



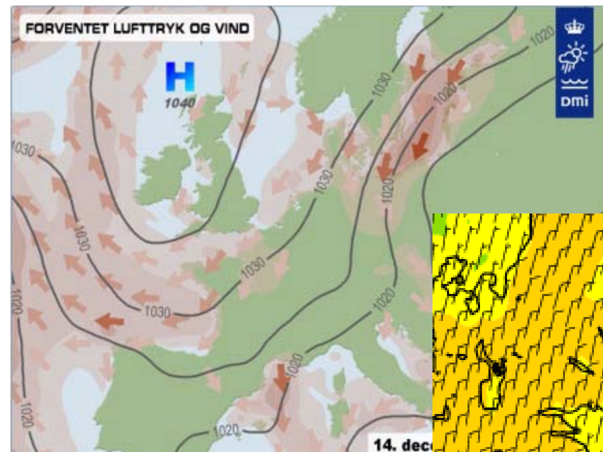
distribution of geostrophic winds (speed & direction) and stability

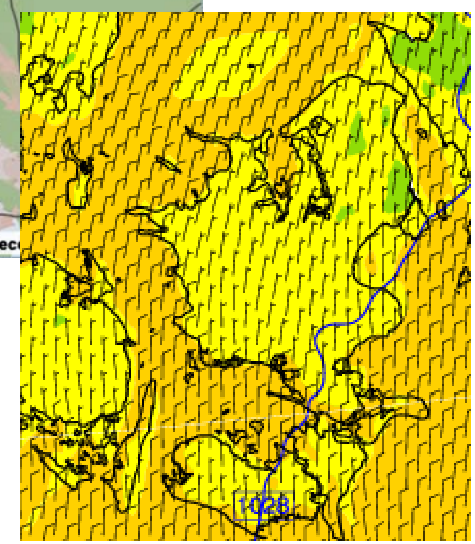
Assumptions used in statistical downscaling

- Regional wind climate can be adequately represented by the combination of a finite number of weather "states"



- There is a one-to-one relationship between each of these states and the local wind conditions



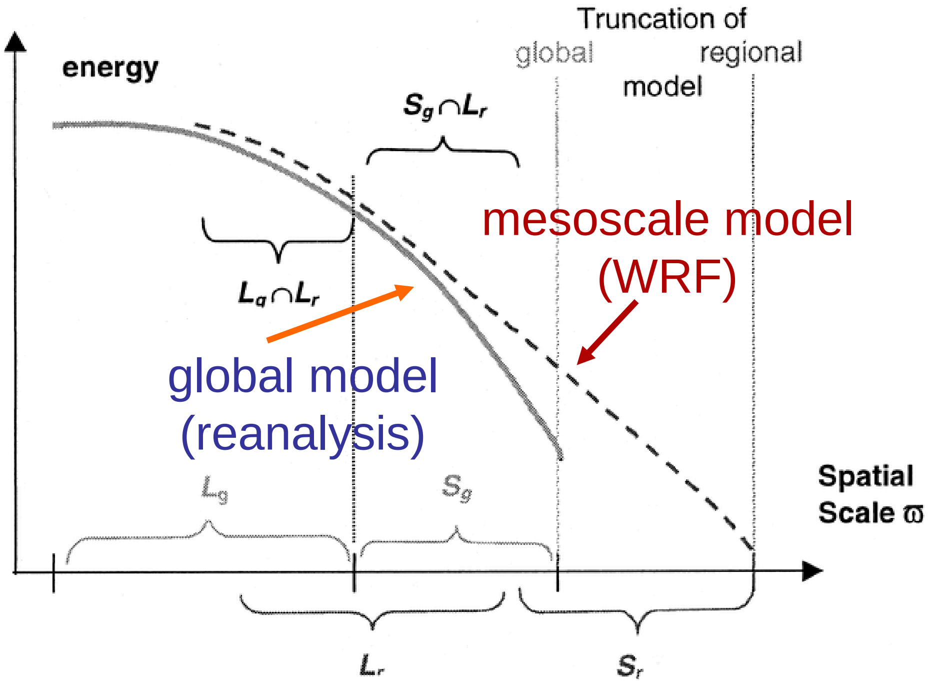


These assumptions break down in regions where strong (thermal) mesoscale forcing exists (sea-breeze, mountain drainage flow, etc.)

Dynamical Downscaling

- Not weather forecasting
- Not regional climate modeling

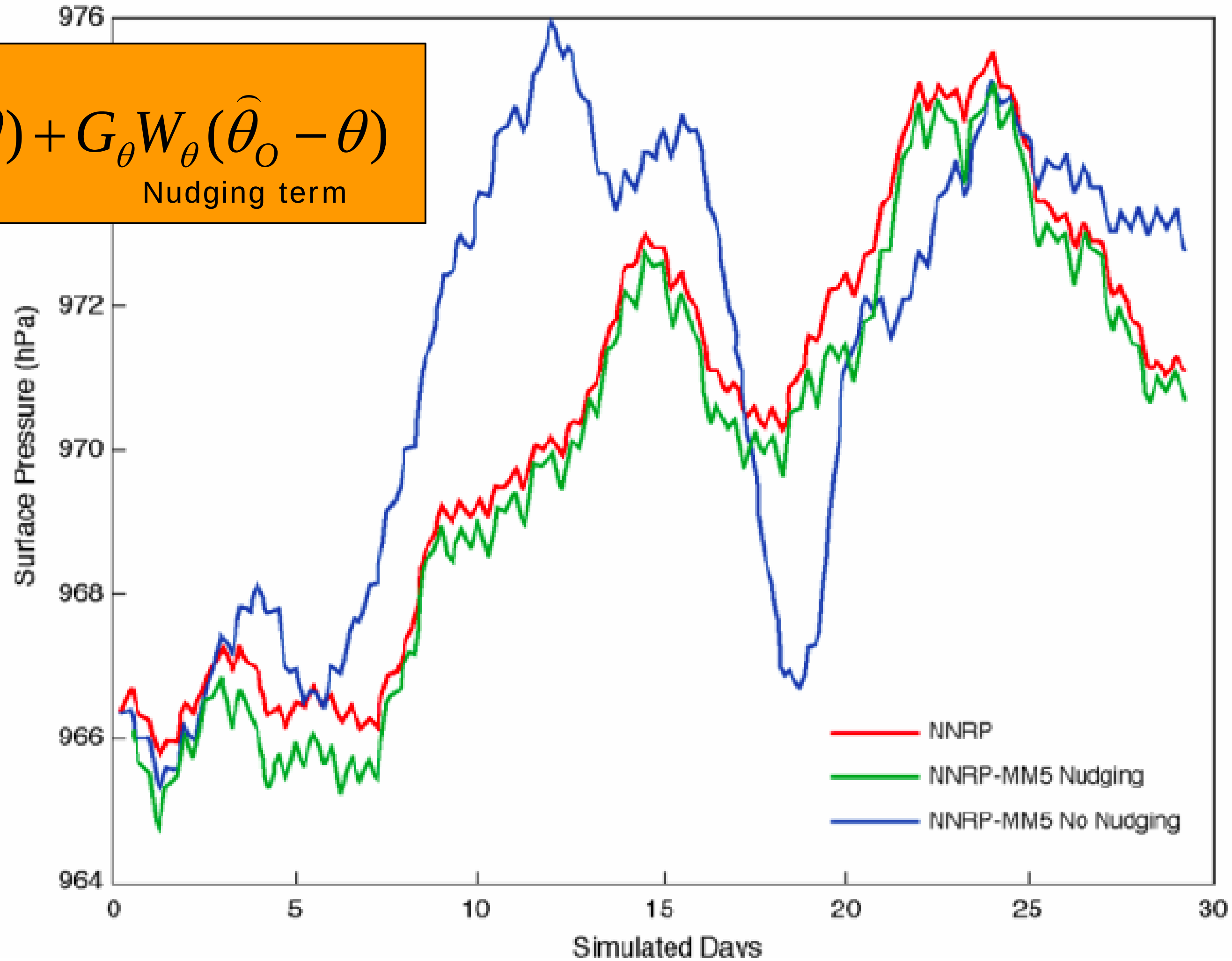
We “trust” the large-scale reanalysis from which the downscaling is based
We need to resolve smaller scales not present in the reanalysis



von Storch et al (2000)

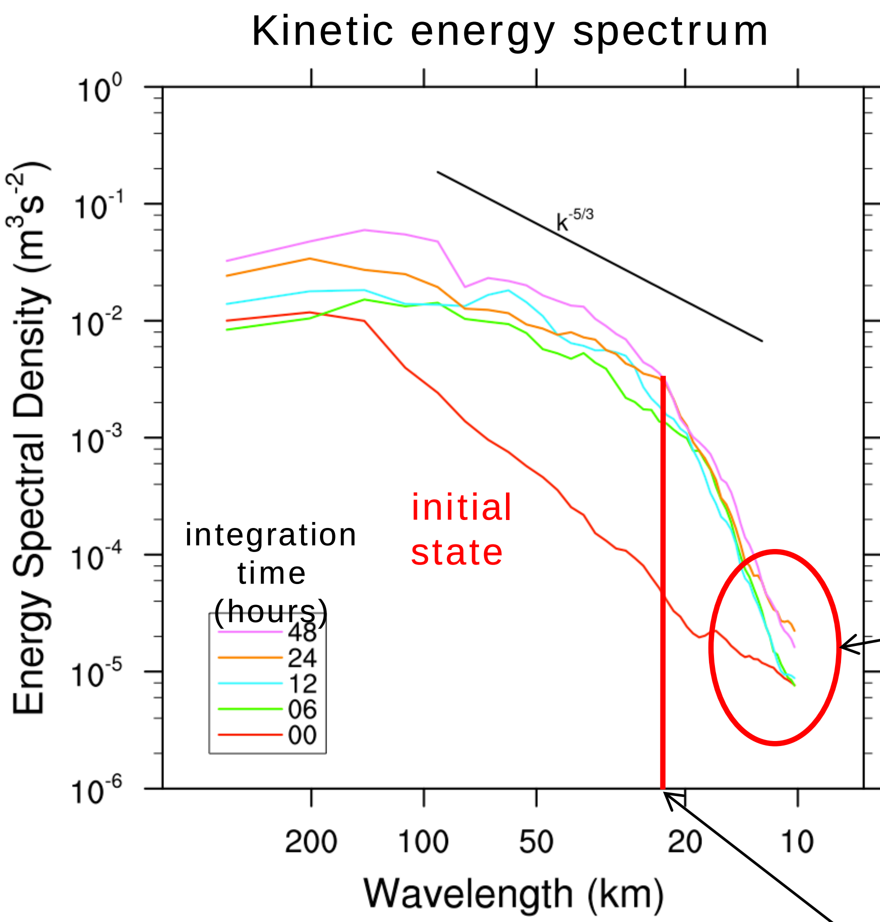
Is the downscaling simulation in sync with the driving analysis?

$$\frac{\partial \theta}{\partial t} = F(\theta) + \underbrace{G_\theta W_\theta(\widehat{\theta}_O - \theta)}_{\text{Nudging term}}$$



Domain-averaged surface pressure for a MM5 run over the Pacific Northwest (USA) - from Clifford Mass, Univ. of Washington

Spin-up and resolution effects



Downscaling run 5 km horizontal resolution grid over Northern Europe

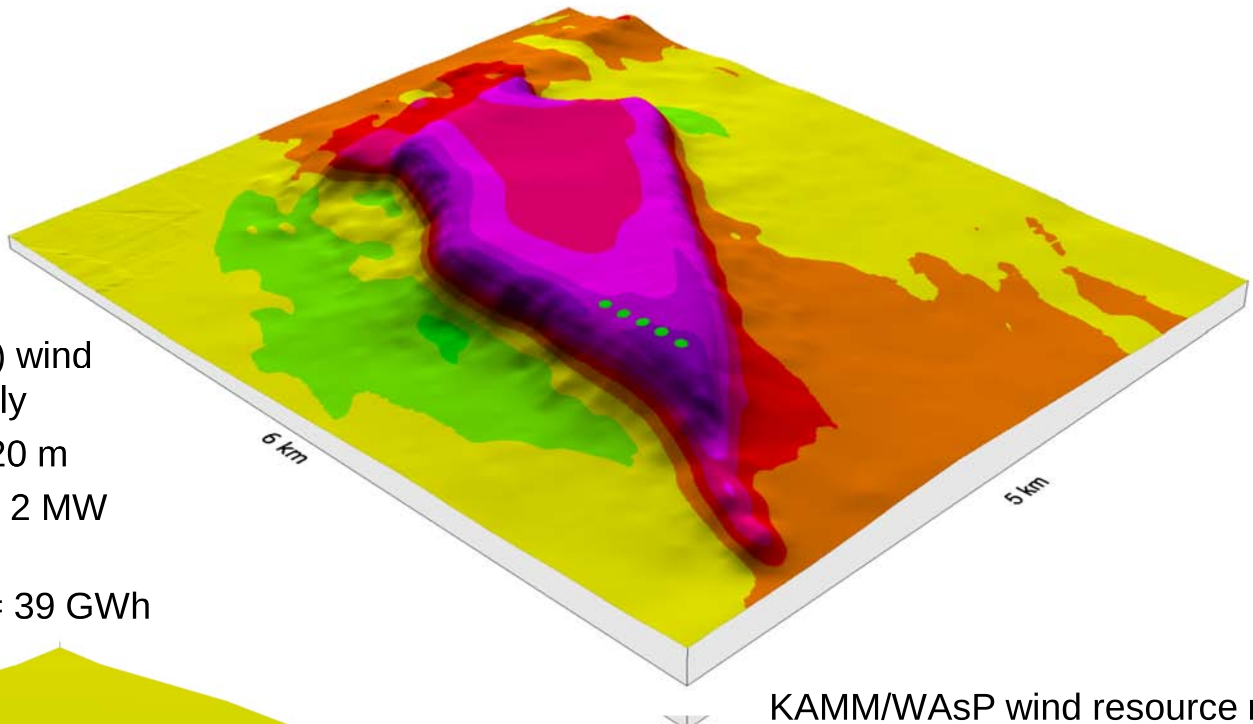
Time required to build up mesoscale structures

Effective resolution ~7 x grid spacing

Many remaining issues…

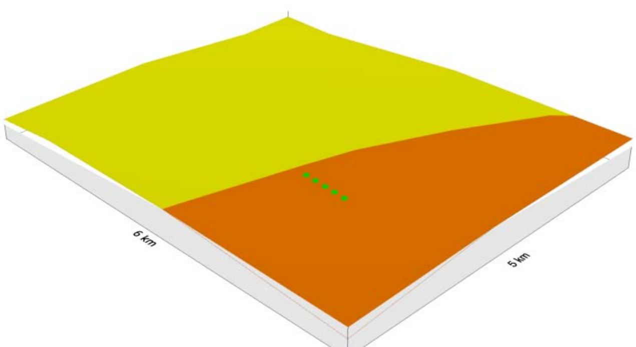
- While dynamical downscaling is often preferred, many issues remain unresolved
  - nudging (strength, level, fields?) versus re-initialization (how often, spin-period length?)
  - length (or sampling strategy) of the simulations – do they capture the interannual (interdecadal) variability?
  - what is de adequate spatial resolution – small enough to capture detailed mesoscale structures, large enough for parameterizations to remain valid
  - since coupling to microscale – avoid double representing small-scale structures
  - ??

Need for mesoscale to microscale downscaling: Resolution is key in applications



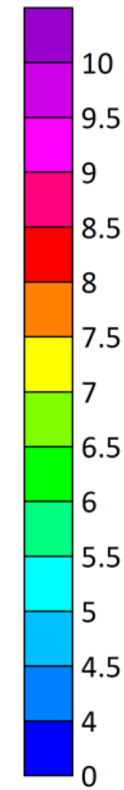
Mesoscale (KAMM) wind resource map only

- Grid cell size 5120 m
- Wind farm of five 2 MW turbines
- Estimated AEP = 39 GWh



KAMM/WAsP wind resource map

- Grid cell size 20 m
- Wind farm of five 2 MW turbines
- Estimated AEP = 55 GWh



wind speed (m/s)

Importance of resolution

Wind resource (power density) calculated at different resolutions

10 km

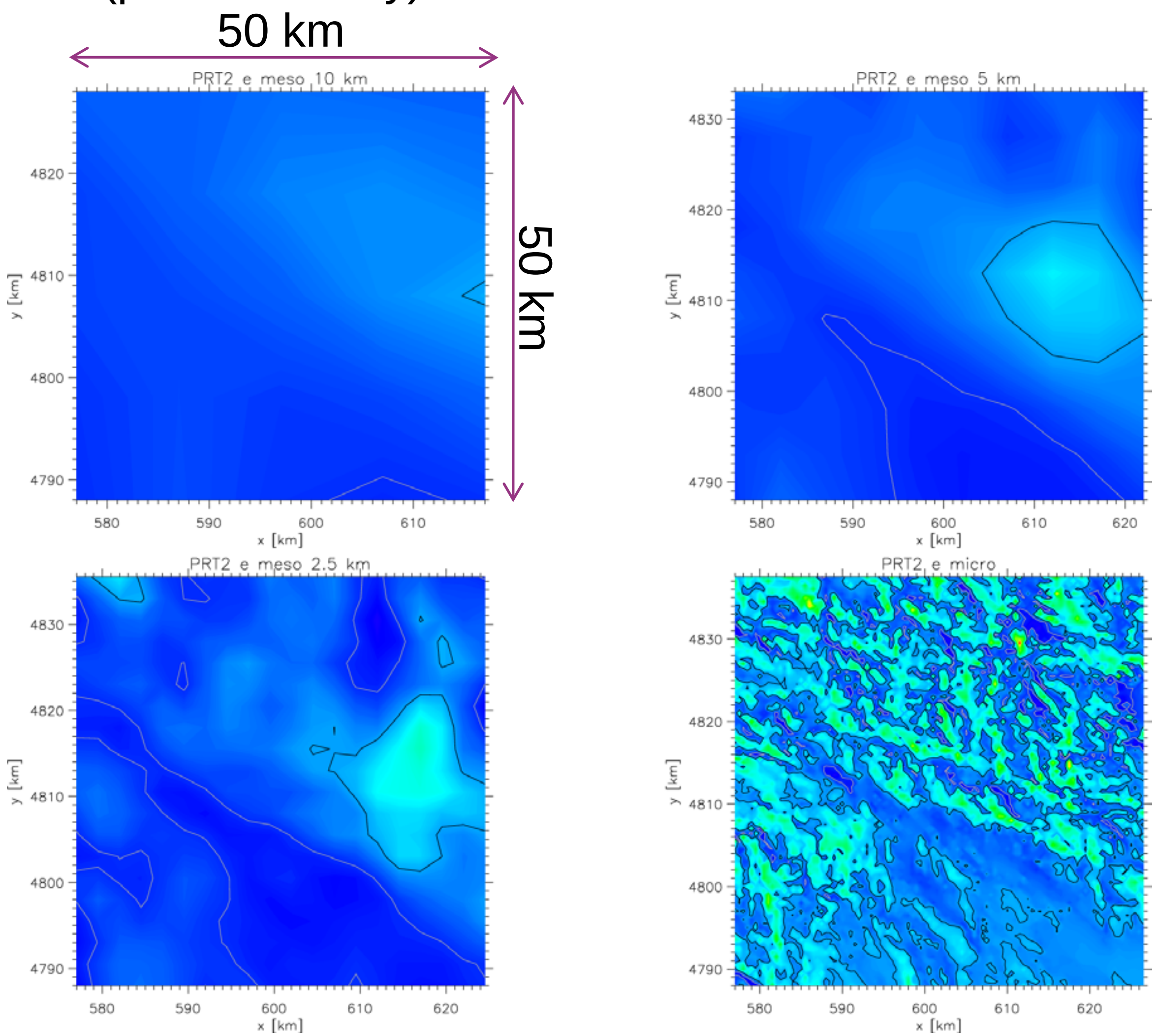
324 W/m^2

378 W/m^2

5 km

328 W/m^2

378 W/m^2



2.5 km

323 W/m^2

378 W/m^2

0.1 km

505 W/m^2

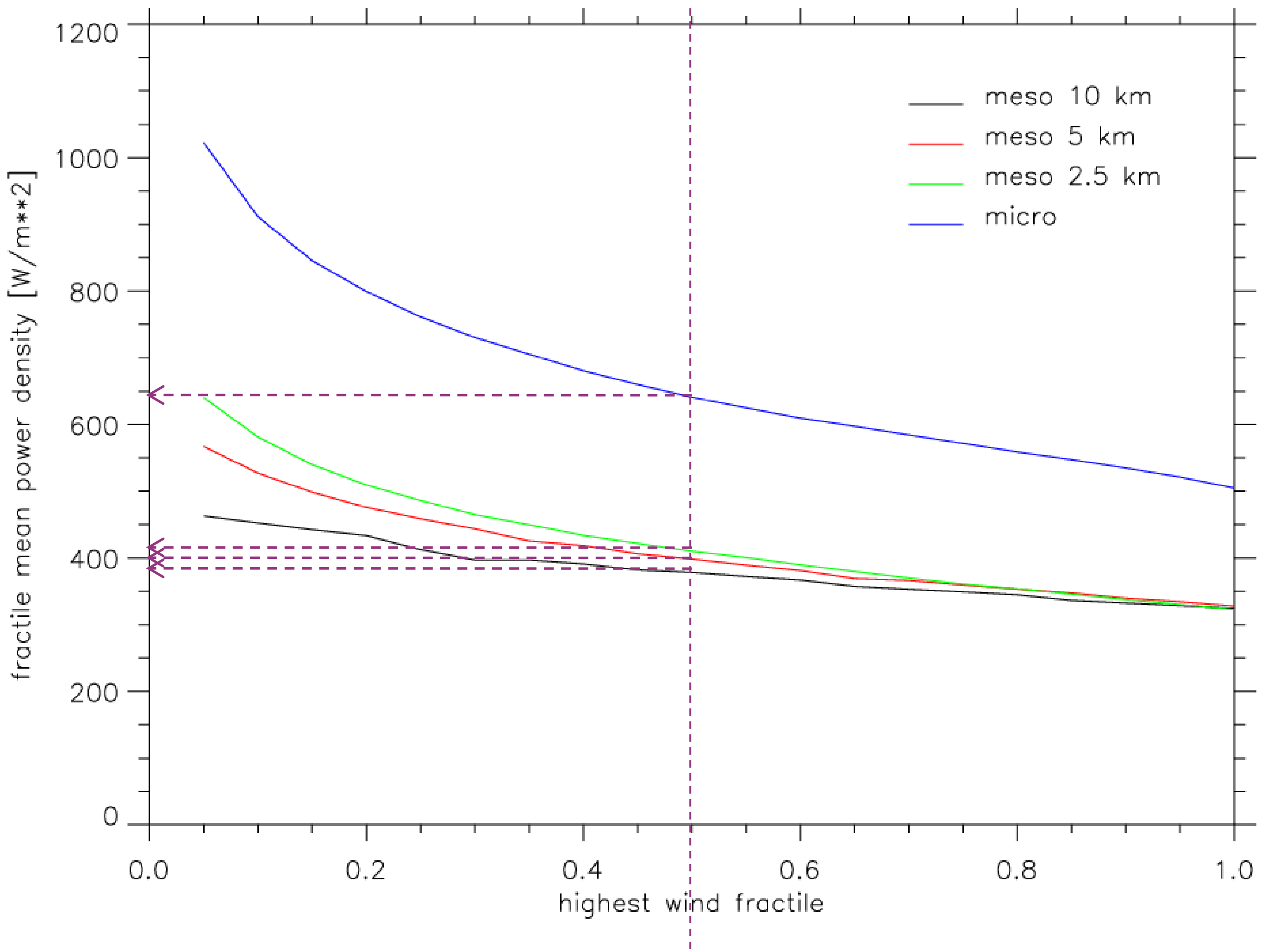
641 W/m^2

mean power density of total area

mean power density for windiest 50% of area

Badger et al (2011)

Importance of resolution

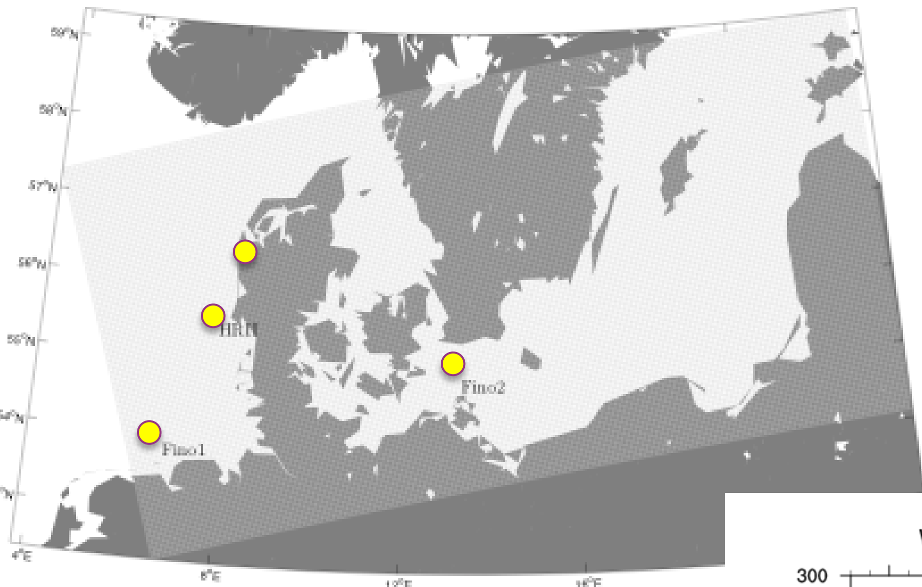


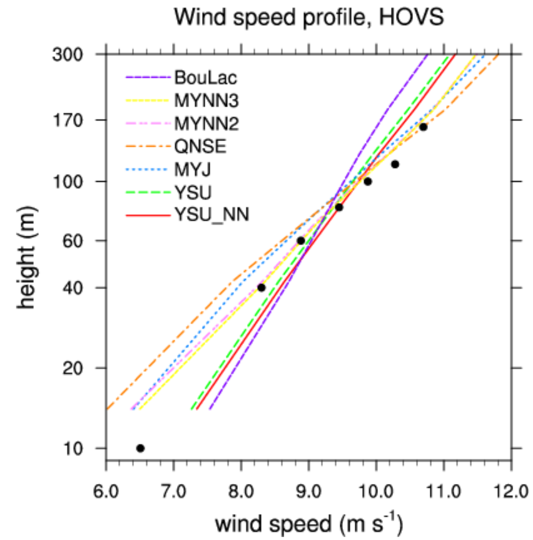
Note: this area exhibits very large topography effects. Even for Danish landscape effect can give 25 % boast in wind resource at the windiest 5 percentile.

Median power density windiest

Badger et al (2011)

Details of the mesoscale model climatology are important to the coupling strategy

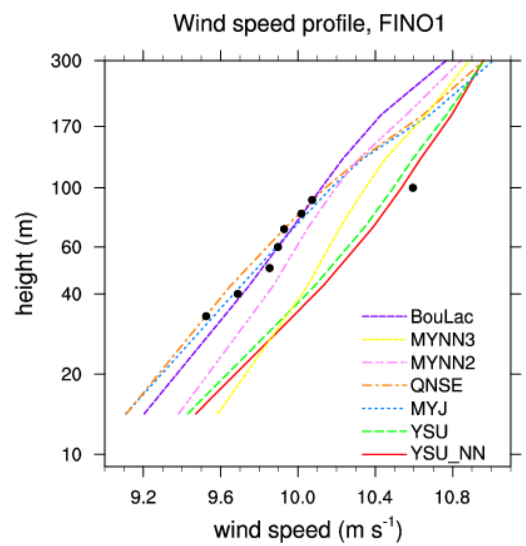


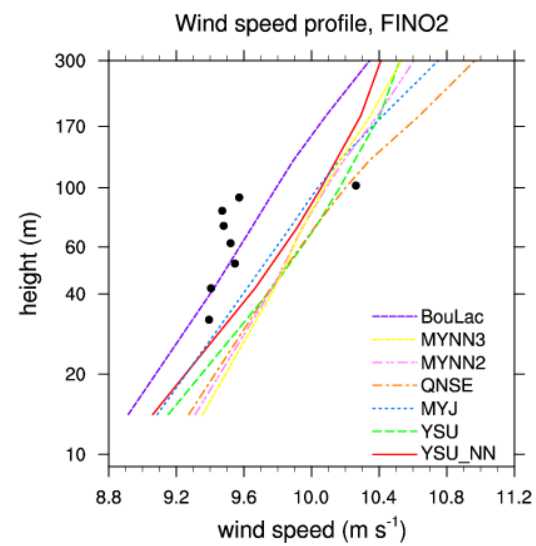


15, 5km dynamical downscaling (WRF) – CFSR reanalysis

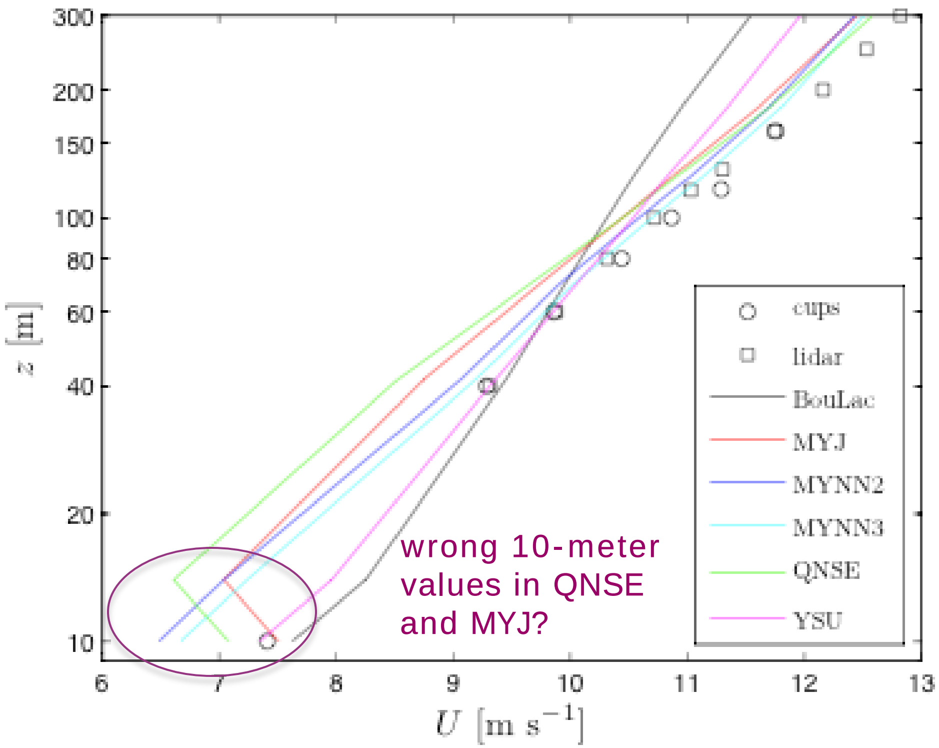
October 2009

6 boundary layer schemes (MYNN2, MYNN3, MYJ, QNSE – KTE schemes, BouLac, YSU - Non-local schemes)

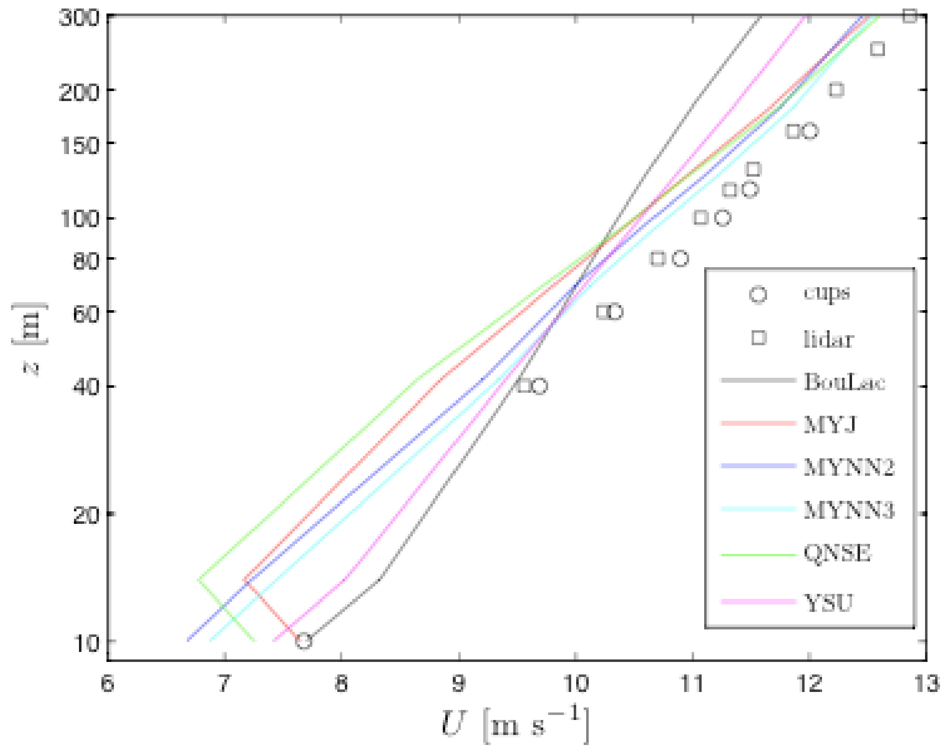




Further profile verification – Comparison with Cups and Lidar data (Høvsøre, October 2009)

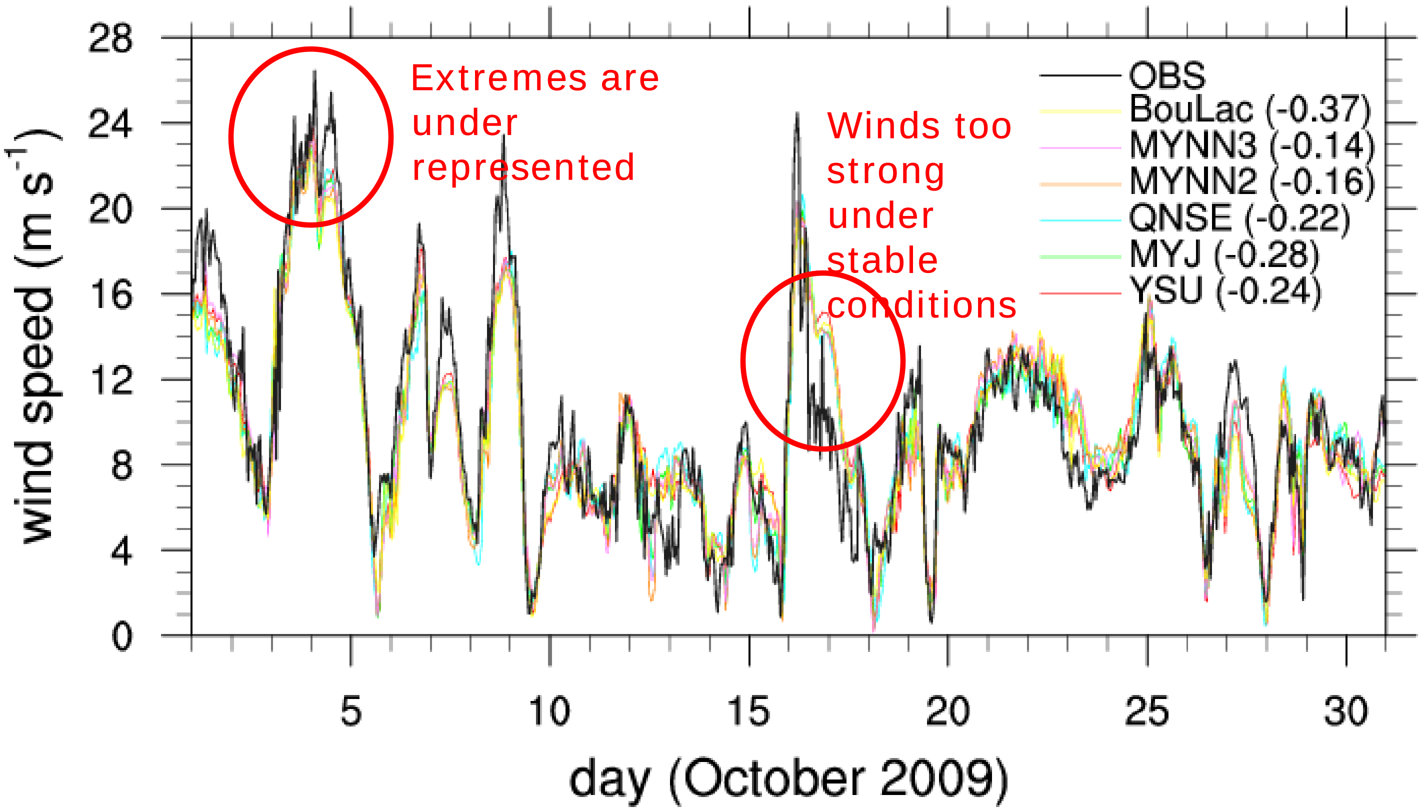


WRF versus wind speed measurements – all sectors



WRF versus wind speed measurements – non-wake sectors

Wind speed, HOVS; height: 100 m



How do we use the knowledge about the errors in the simulation to device a better coupling strategy?

Mesoscale to microscale coupling: Need for generalization

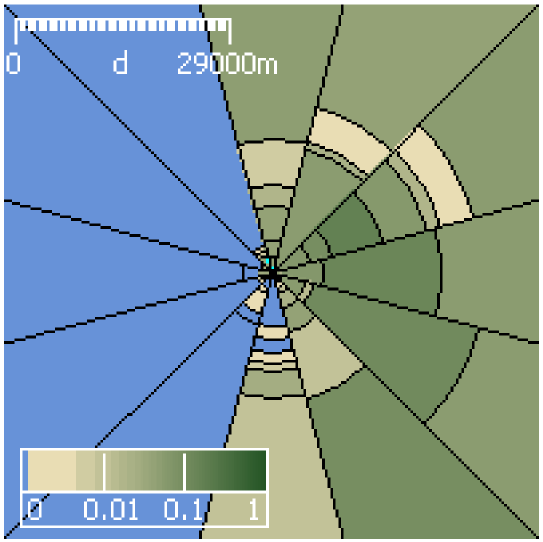
$h(x) = f(x)$ $\quad$ $f(x) \neq g(x)$ $\quad$ $h(x) = g(x)$

$z_0(x) = r(x)$ $\quad$ $r(x) \neq s(x)$ $\quad$ $z_0(x) = s(x)$

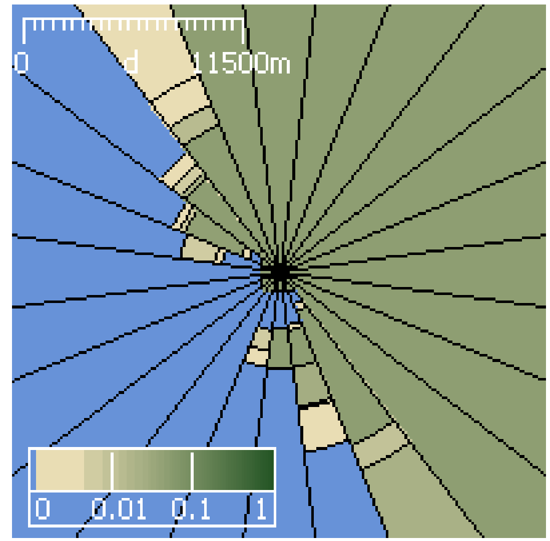
Jake Badger

Høvsøre, Denmark

roughness rose from
high-resolution maps



roughness rose from
WRF land use



To standardize measurements and model values are "corrected" using:

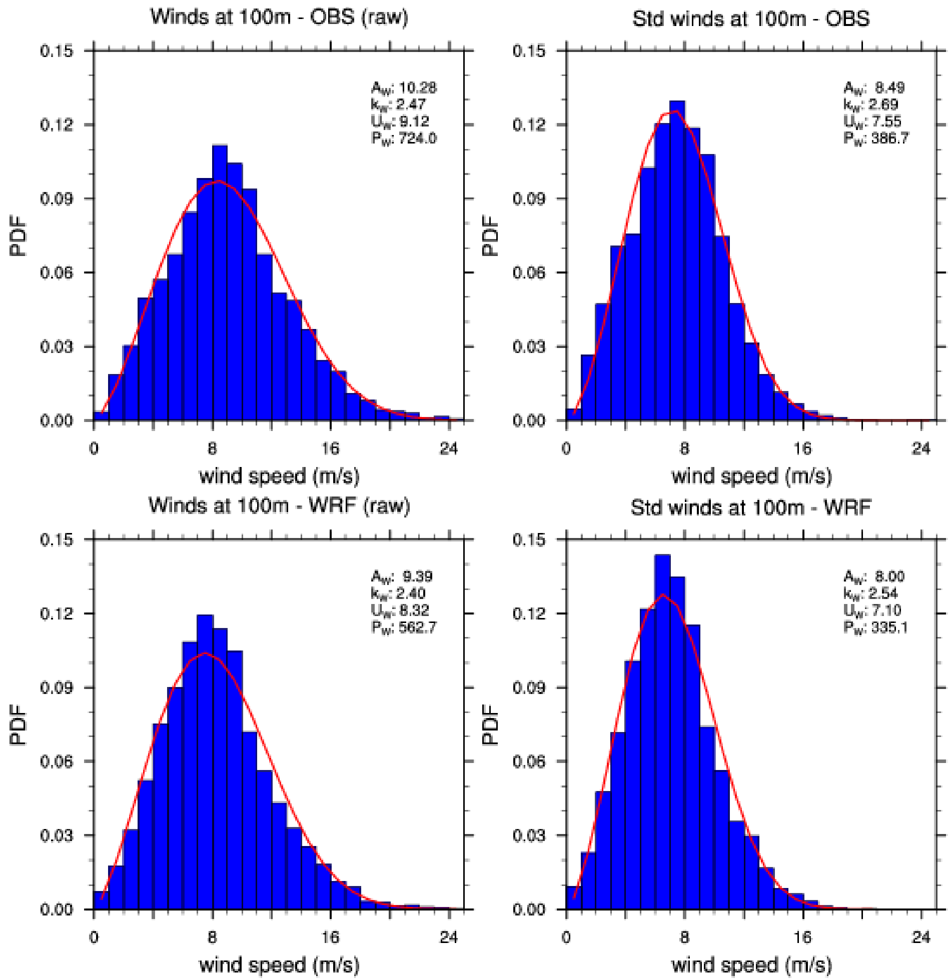
- WAsP speed-up factors (roughness and topography)
- Logarithmic and "geostrophic" wind laws

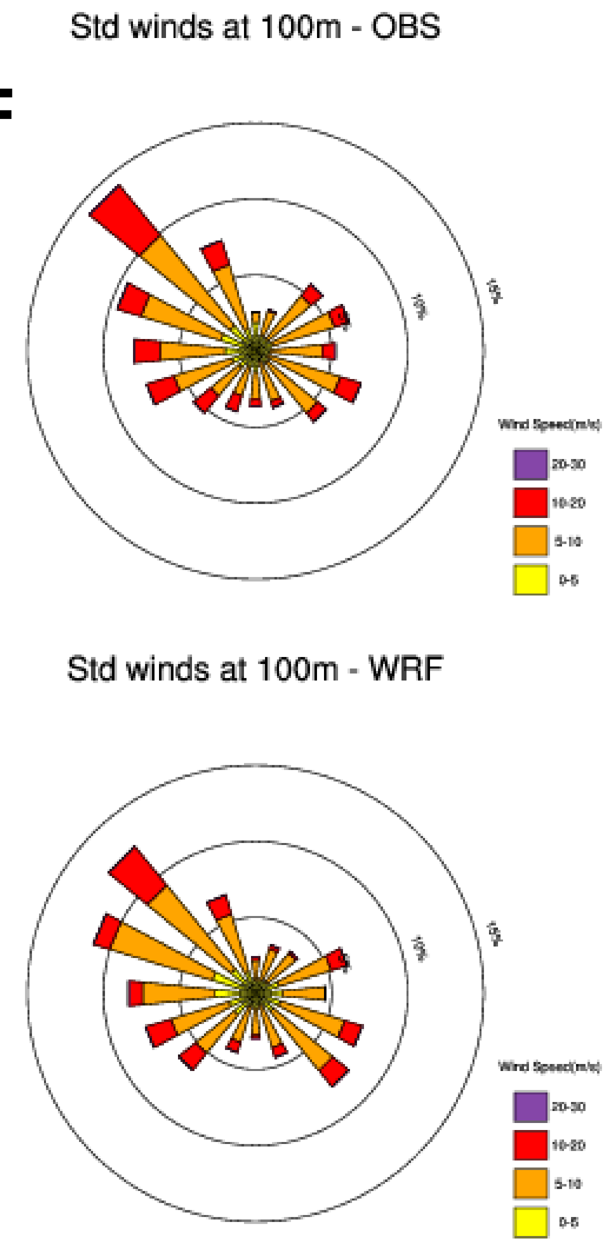
$$u_z = u_{0z}/[(1+s_0)(1+s_r)]$$

$$u_* = \frac{\kappa}{u_z} ln(z/z_0)$$

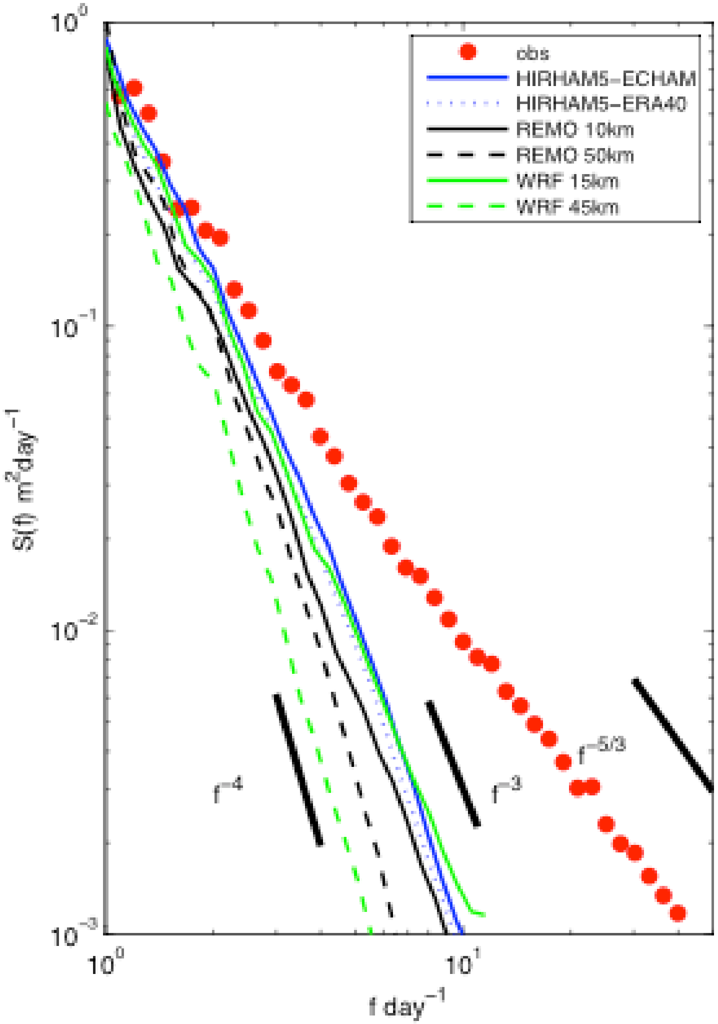
$$G = \frac{u_*}{\kappa}\sqrt{ln\left(\frac{u_*}{f z_0} - A\right)^2 + B^2}$$

Example of wind generalization for Høvsøre mast measurements and WRF

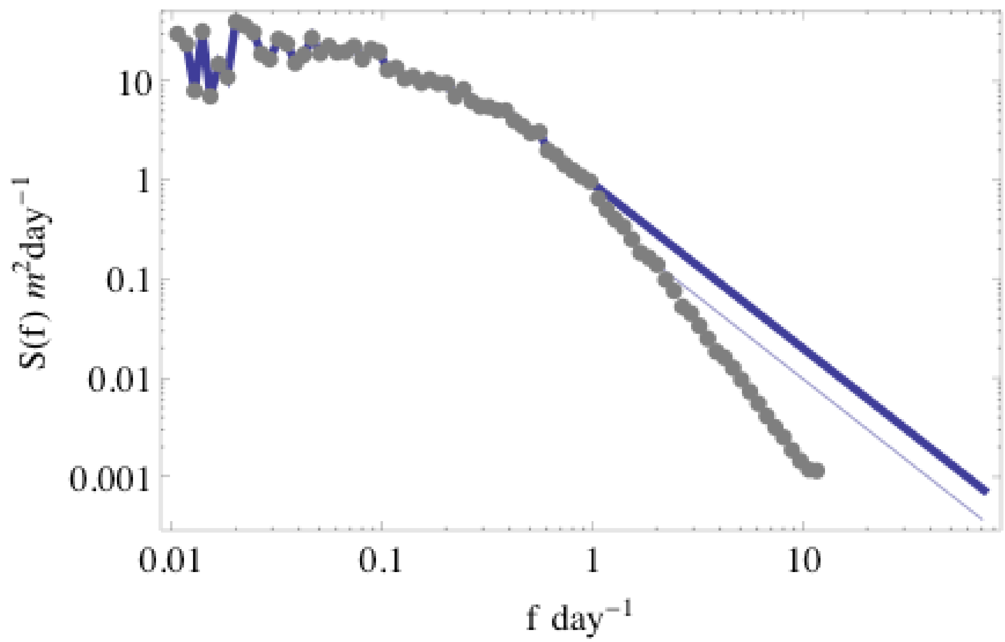




Other applications – Extreme wind estimation from mesoscale model output



Spectra of wind speed at Horns Rev from observations of various model simulations



Modification of the spectrum of the hourly simulated wind speed

Larsén et al. 2011

Many remaining issues…

Large-scale to mesoscale coupling:

- nudging (strength, level, fields?) versus re-initialization (how often, spin-period length?)
- length (or sampling strategy) of the simulations – do they capture the interannual (interdecadal) variability?
- what is de adequate spatial resolution – small enough to capture detailed mesoscale structures, large enough for parameterizations to remain valid
- since coupling to microscale – avoid double representing small-scale structures
- ??

Mesoscale to microscale coupling:

- Coupling to linearized models (i.e., WAsP):
  - Generalization works well on wind climatologies – how to expand the concept to include individual observations and model results (need to cover ever more scales…)
  - How do we make use of the deficiencies in the model simulations?
  - ??
- Coupling to more advanced flow models?